NIF

Image Analysis Algorithms for the ARC Grating Tilt Sensor

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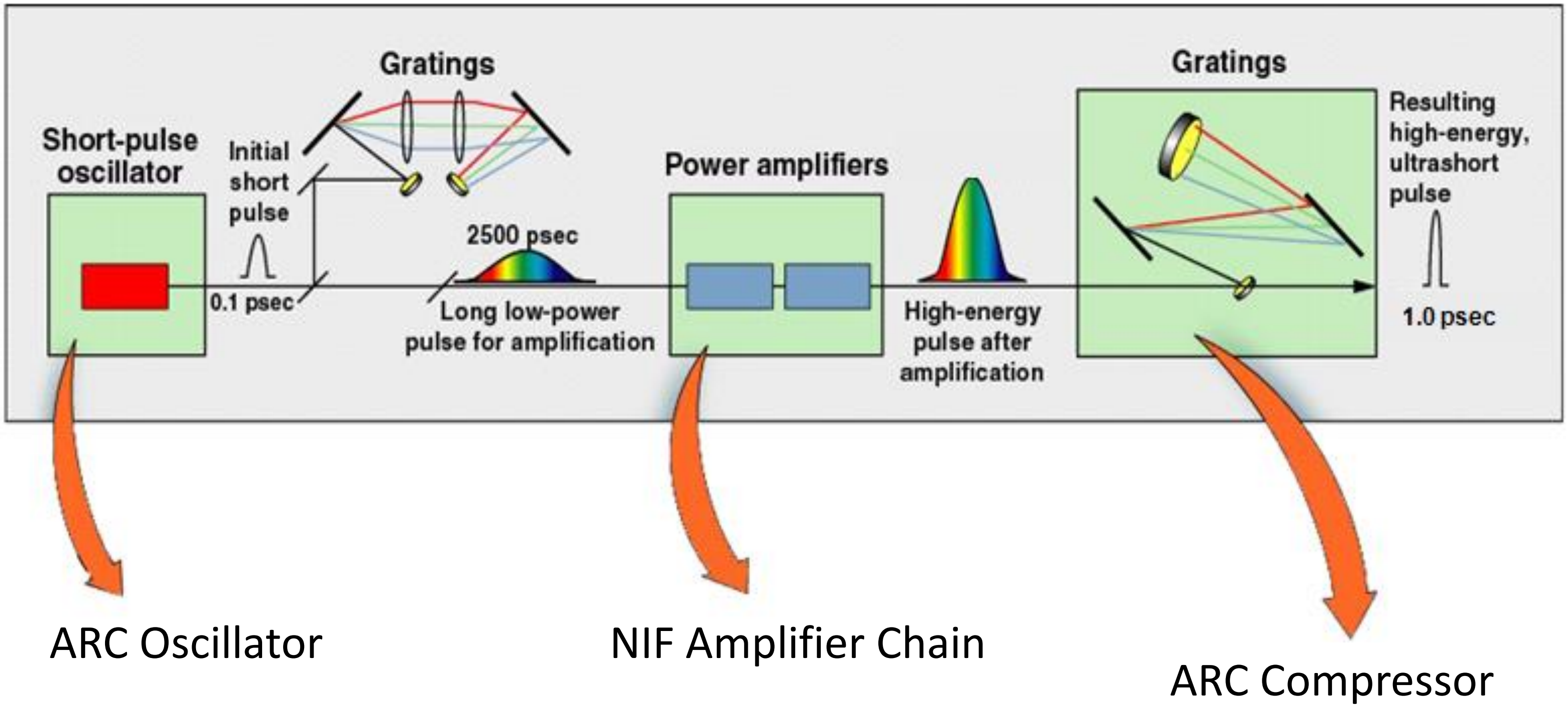
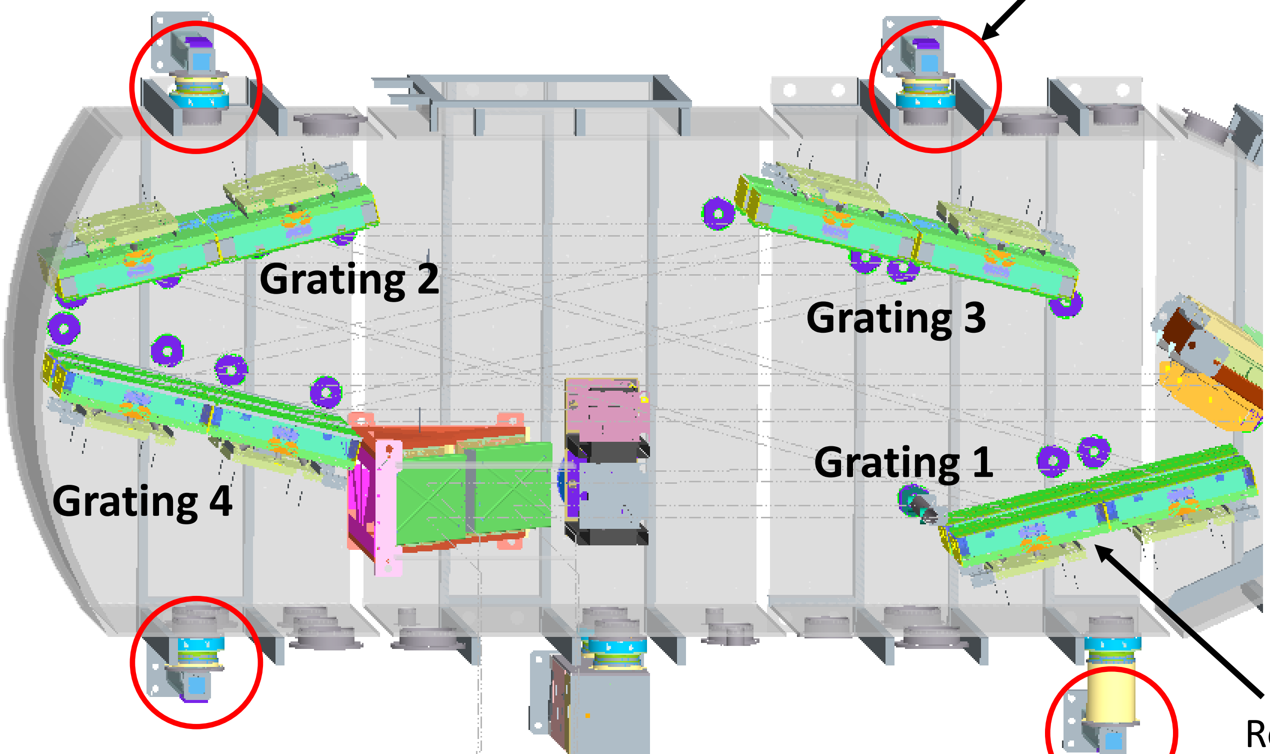
The Advanced Radiographic Capability (ARC) is a laser system designed to produce a sequence of short pulses used to backlight imploding fuel capsules

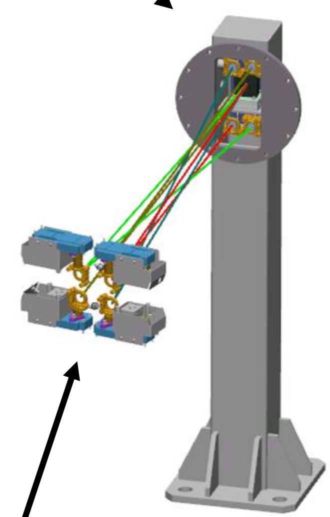


Graphic courtesy G. Brunton, et al., 'Advanced Radiographic Capability (ARC) Computer Controls for the National Ignition Facility (NIF),' *8th IAEA Technical Meeting on Control, Data Acquisition and Remote Participation for Fusion Research*, June 20-24, 2011

The tilt of ARC Gratings are monitored using a mirror mounted outside of the vacuum compressor vessel

Four lasers, cross-hair and camera mounted on tilt sensor post outside compressor vessel

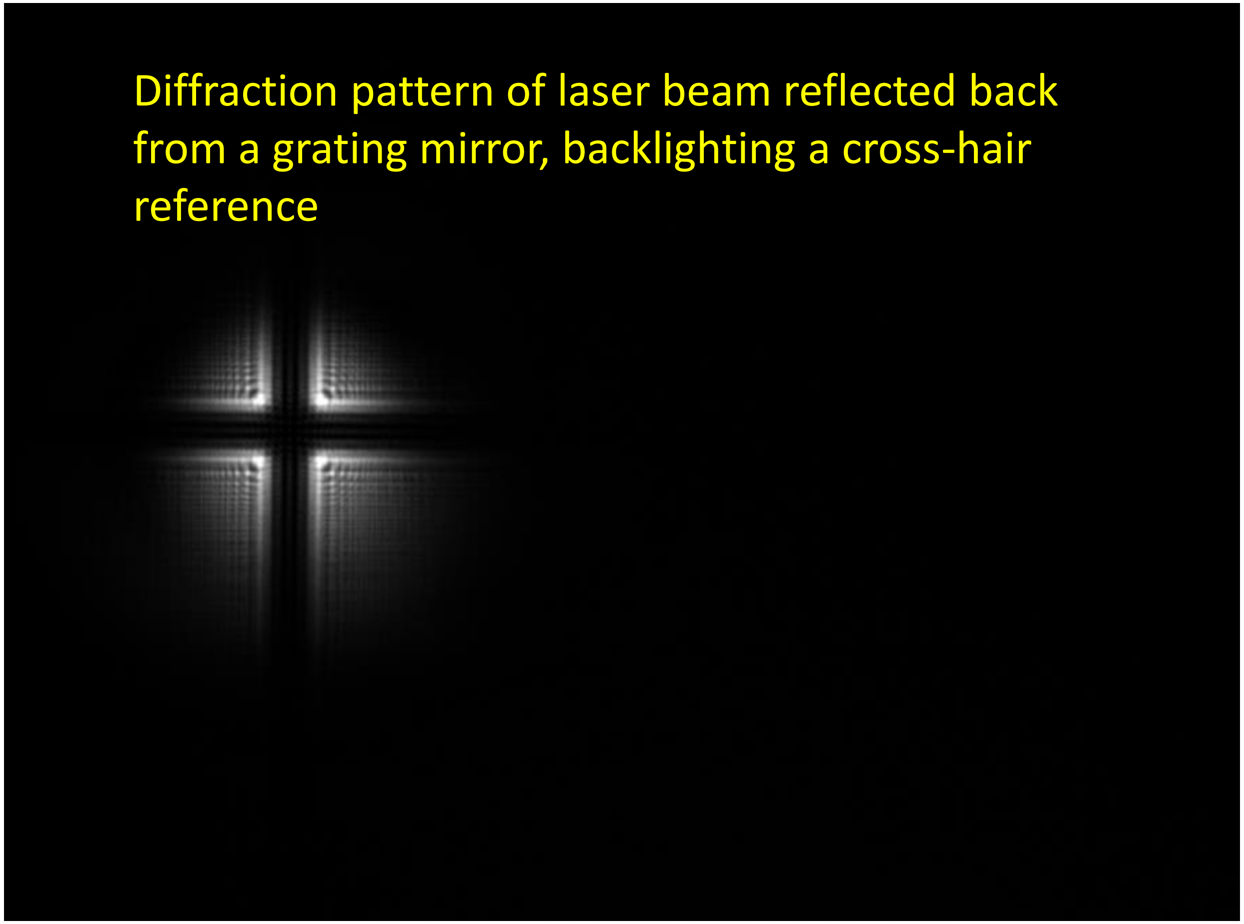




Retro-reflectors mounted on back of gratings inside compressor vessel

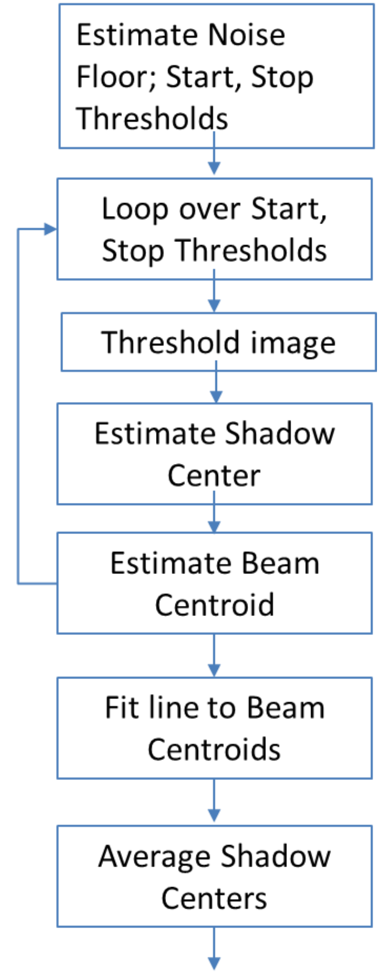
ARC Vacuum Compressor Vessel

An out-of-tolerance change in the displacement of beam center relative to its backlighted cross-hair indicates drift of ARC Grating alignment, which must be corrected before a shot



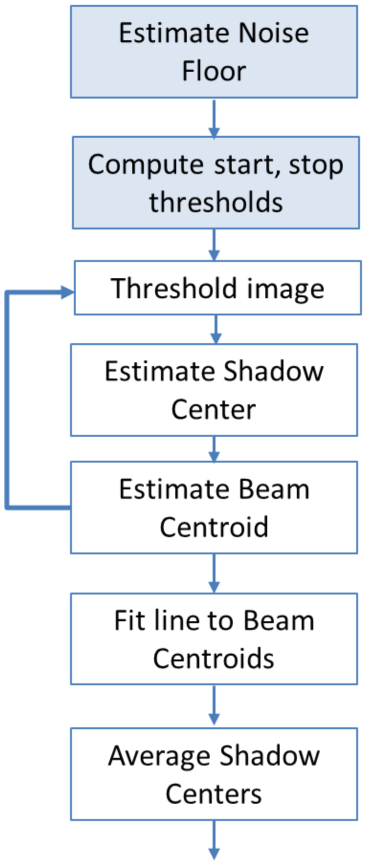
Algorithm design considerations

- Algorithm must be robust. Cost of a false alarm could potentially delay shots
- Sub-pixel accuracy is required to meet performance requirements
- Nature of diffraction pattern makes it difficult to localize edges
- Computational resources and timeliness of execution limit computational complexity of algorithm
- System is under development. Use synthetic and incidentally acquired imagery for algorithm development
- The orientation of the shadow is fixed

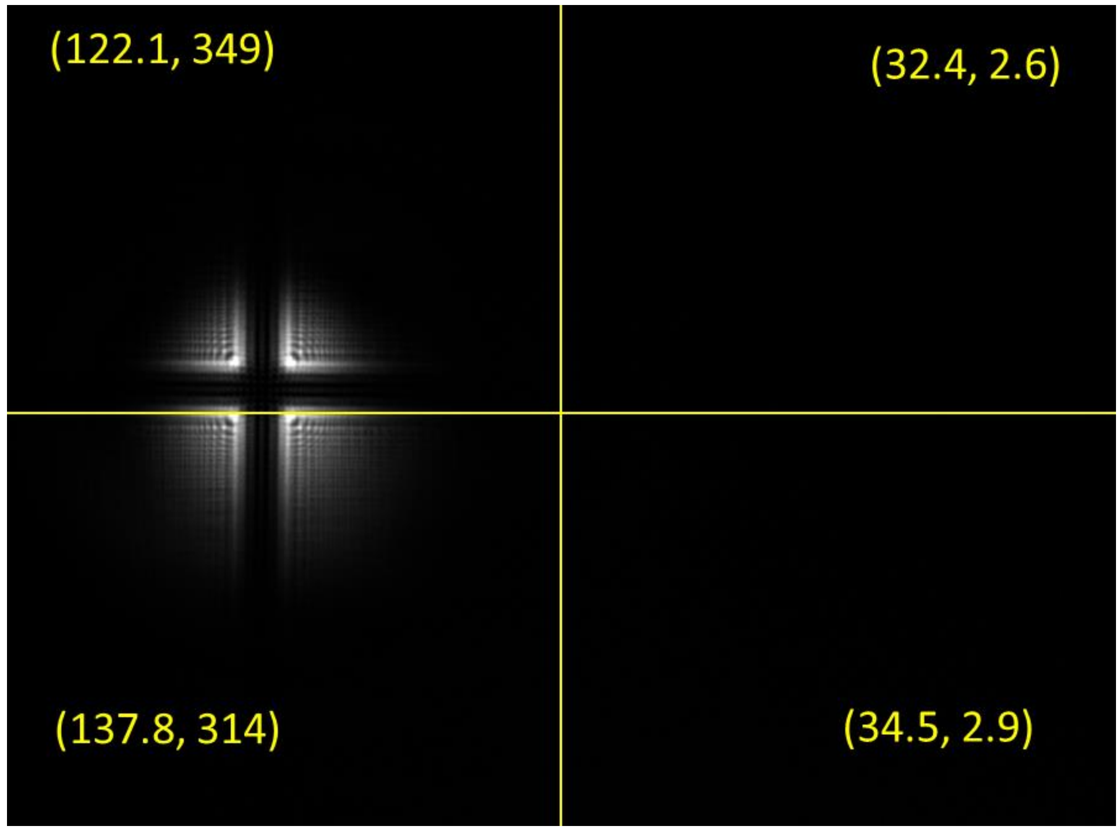


→ *Binary image processing, lots of averaging*

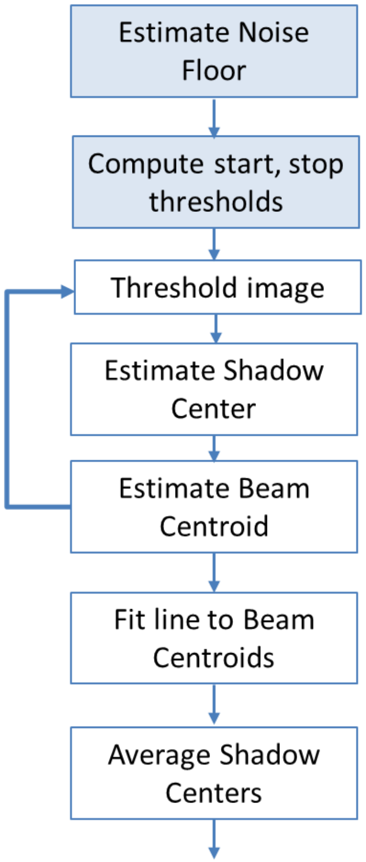
Step 1a: Estimate Noise Floor (μ, σ) in quadrants



Estimates of beam centroid, location of reference pixel

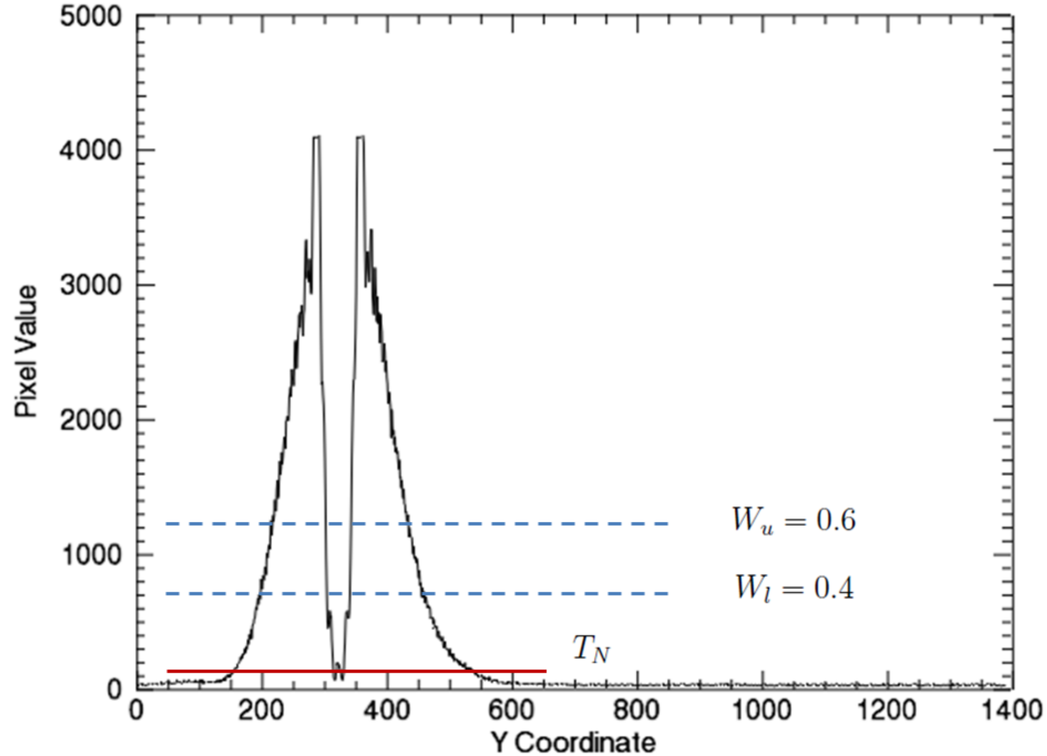


Step 1b: Determine Start, Stop Thresholds



Estimates of beam centroid, location of reference pixel

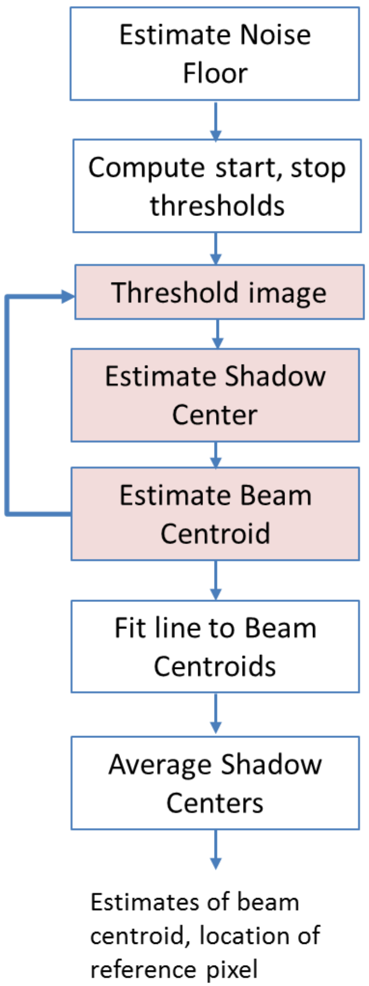
Line out of beam

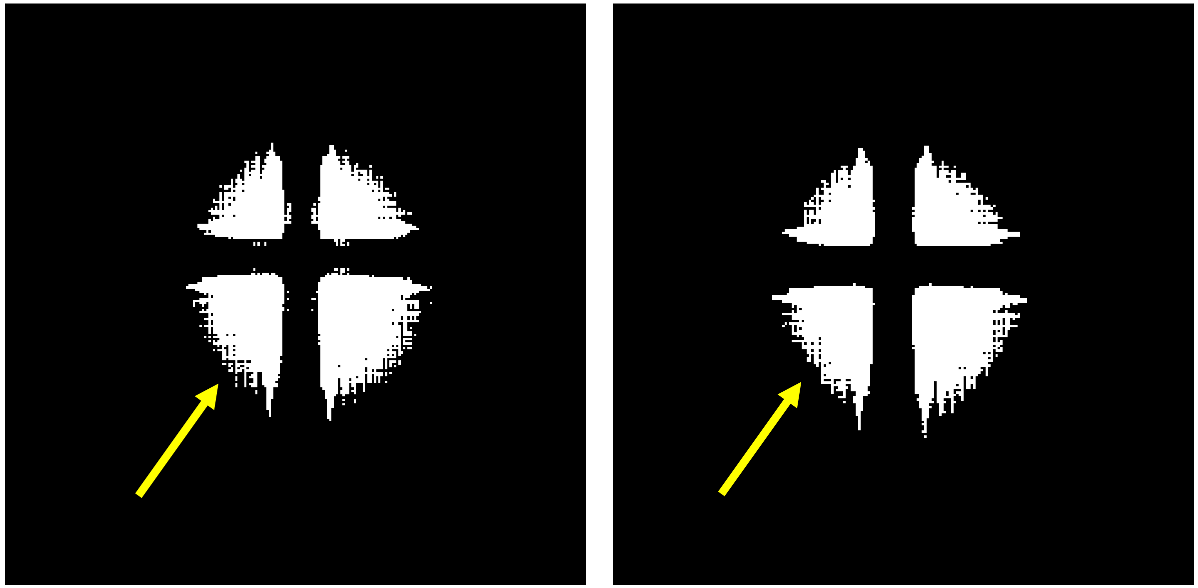


$$W_i = \frac{\sum_{(x,y)\in\mathcal{R}}[I(x,y) \leq T_i]I(x,y)}{\sum_{(x,y)\in\mathcal{R}}[I(x,y) \geq T_N]I(x,y)}$$

$$\begin{aligned} i &= \arg\min_i \{\mu_i\} \\ T_n &= \mu_i + 4\sigma_i \end{aligned}$$

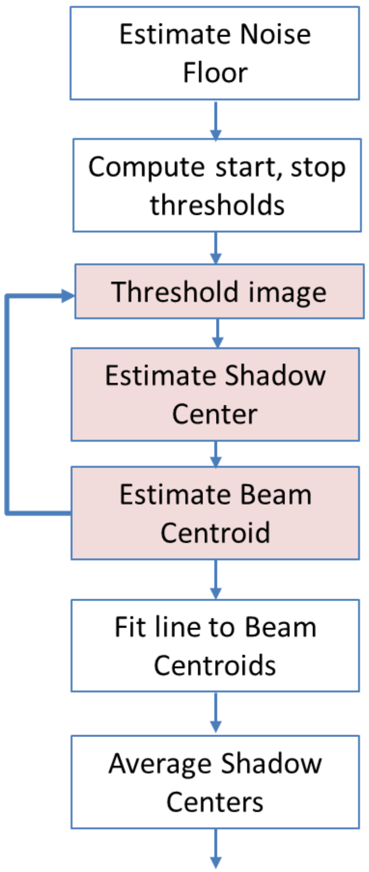
Step 2a: Threshold image, prune small regions on boundary of diffraction pattern



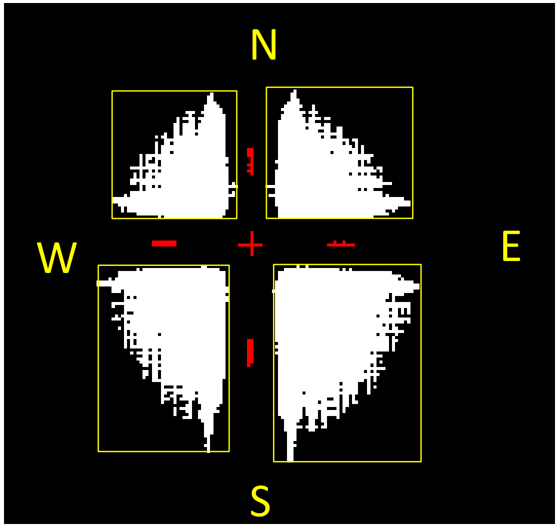


1. For threshold T_i, create binary image $B(x, y)$ where $B(x, y) = 1$ for $I(x, y) > T_i$ for all (x, y)
2. Label N regions in $B(x, y)$ as R_i where $i = 1, 2, \ldots, N$
3. Determine number of pixels A_i associated with each region R_i
4. If $A_i \leq T_A$ then set the pixels in R_i to zero

Step 2b: Estimate center of shadow '+' in diffraction pattern (called the reference pixel)



Estimates of beam centroid, location of reference pixel



1. Estimate the centroids of the blobs (x_{NE}, y_{NE}), (x_{SE}, y_{SE}),(x_{NW}, y_{NW}), and (x_{SW}, y_{SW}). Form a bounding box around each blob, and let M_b be the minimum edge length over all bounding box sides

2. Set $L = 0.2M_b$ where L is the length of averaging when we estimate the x- and y-coordinates of the shadow center (x_s, y_s)

3. Estimate value x_s as the average of the Northern and Southern gap widths (edge-to-edge distance between blobs) averaged over a region of y-coordinates.

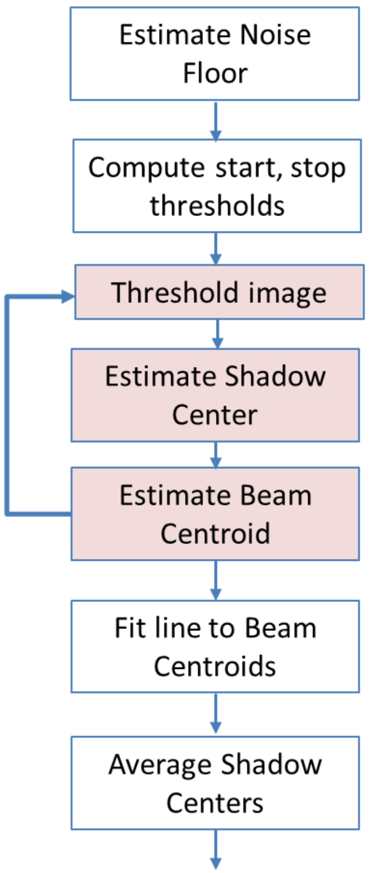
   (a) For the Northern gap, find the set $\{x_n\}$ of x-coordinates that are the mid-point between the edges of the Northeast and Northwest blobs over the range $-L_a/2 + y_N < y < L_a/2 + y_N$ where $y_N = \min\{y_{NE}, y_{NW}\}$

   (b) For the Southern gap, find the set $\{x_s\}$ that are the mid-point between the edges of the Southeast and Southwest blobs over the range $-L_a/2 + y_S < y < L_a/2 + y_S$ where $y_S = \max\{y_{SE}, y_{SW}\}$

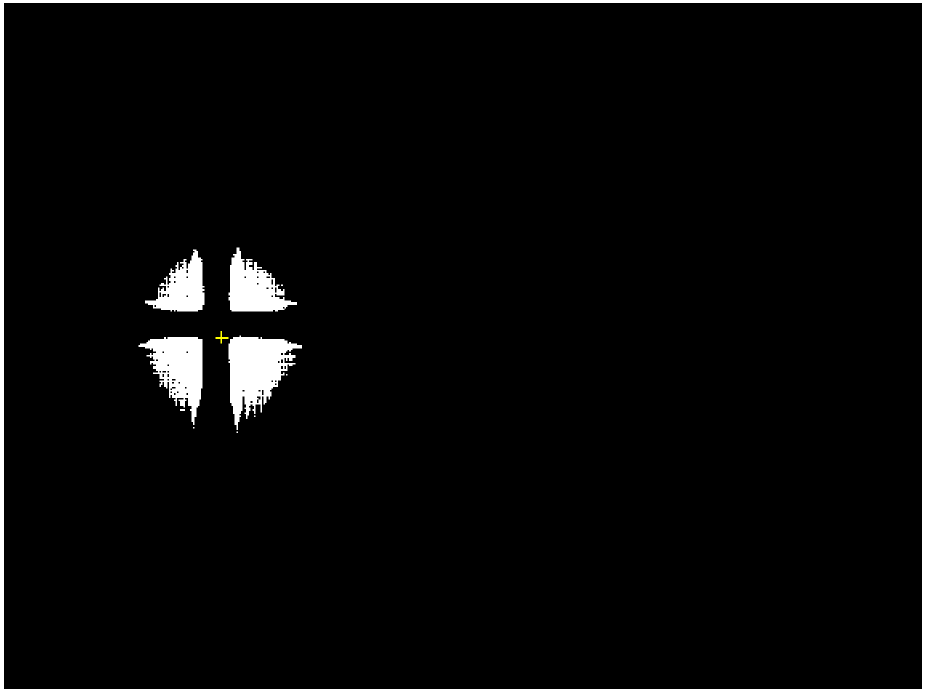
   (c) Estimate the x-coordinate of the shadow as $x_s = \langle\{x_n\}, \{x_s\}\rangle$

4. Estimate value y_s using the Eastern and Western gap widths in a manor similar to that used to estimate x_s

Step 2b: Estimate centroid of beam



Estimates of beam centroid, location of reference pixel



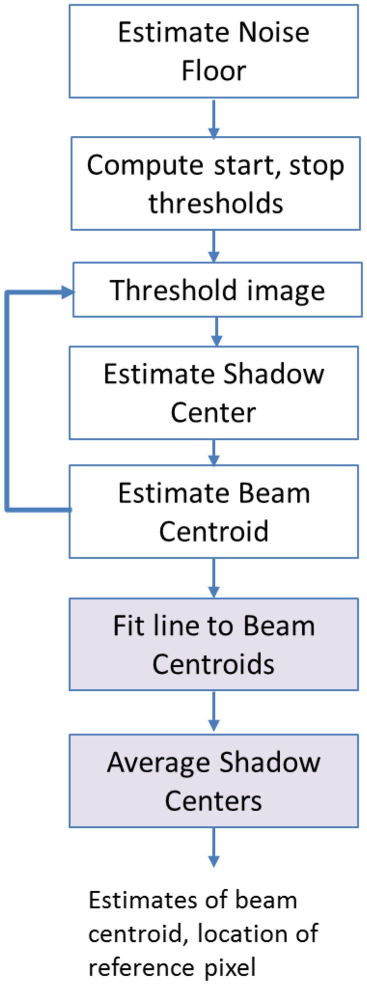
$$
\begin{aligned}
X_b &= \frac{\sum_x (\sum_y B(x,y))x}{\sum_x \sum_y B(x,y)} \\
Y_b &= \frac{\sum_y (\sum_x B(x,y))y}{\sum_x \sum_y B(x,y)}
\end{aligned}
$$

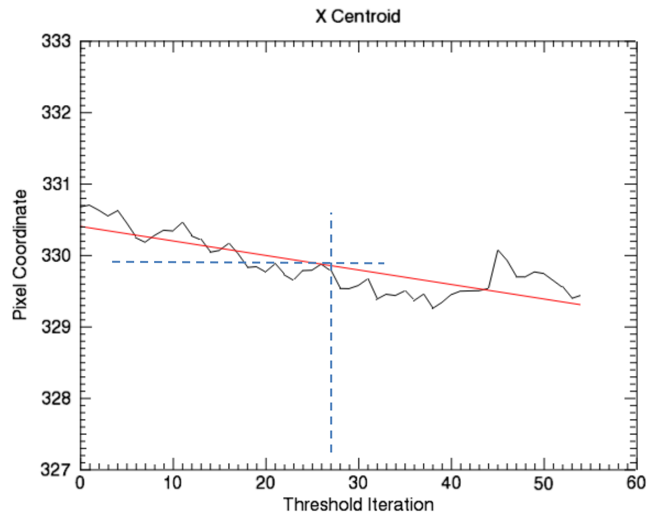
$$B(x,y) = [I(x,y) \geq T]$$

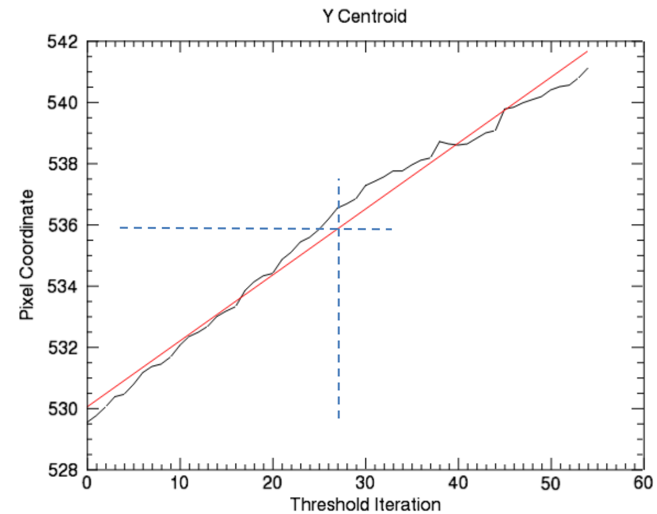
Beam centroid is the geometric centroid of the binary image

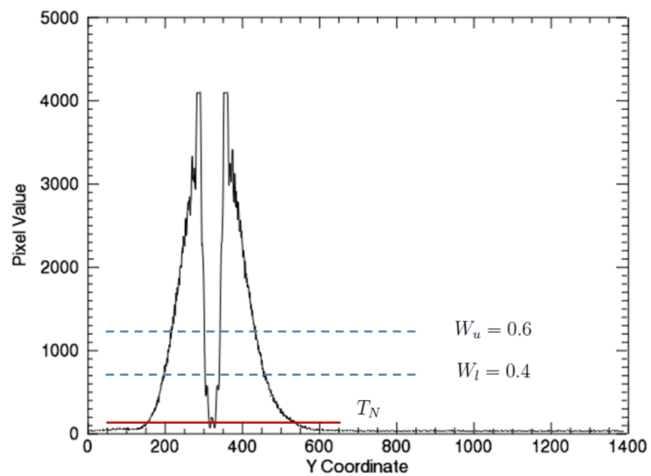
Fast and simple

Step 3a: Fit least squares line to (x, y) estimates of beams centroid



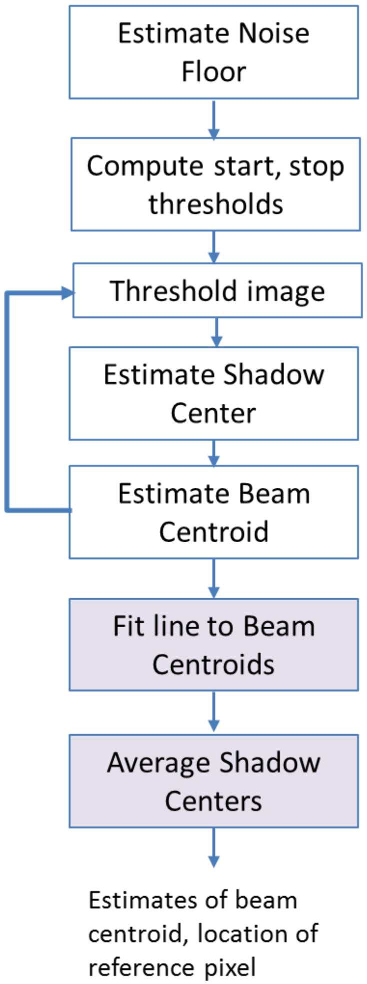


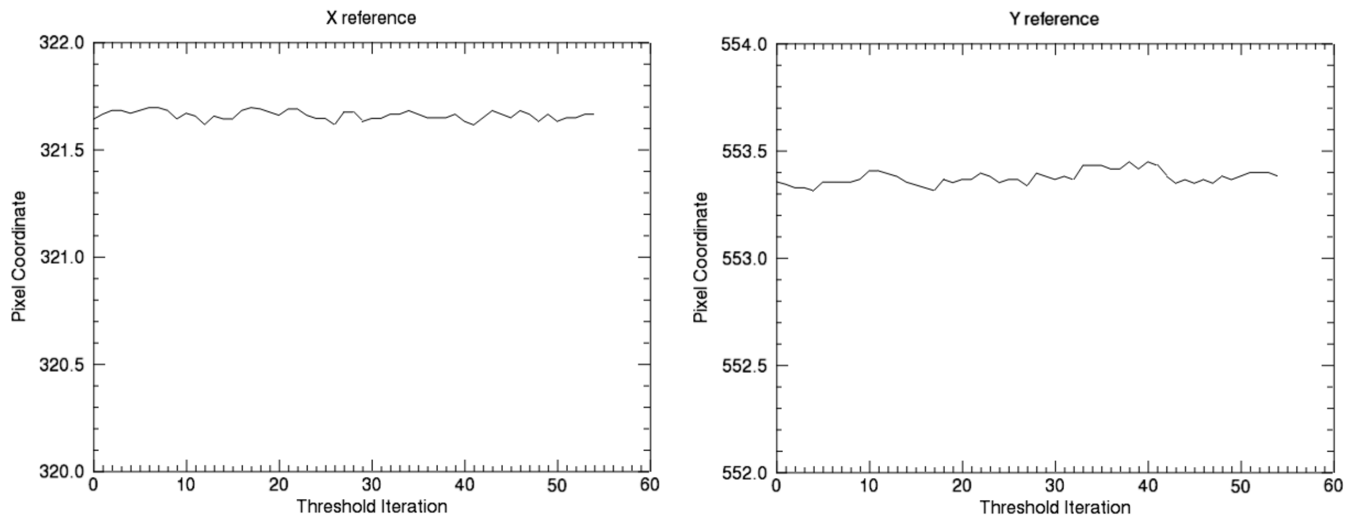




It was found that the coordinates of the centroid of the thresholded image was a function of threshold. We modeled this relationship as a linear model, and use the mid-threshold value as the centroid coordinates

Step 3b: Simple average of (x, y) estimates of reference pixel will do for shadow centers (reference pixel)





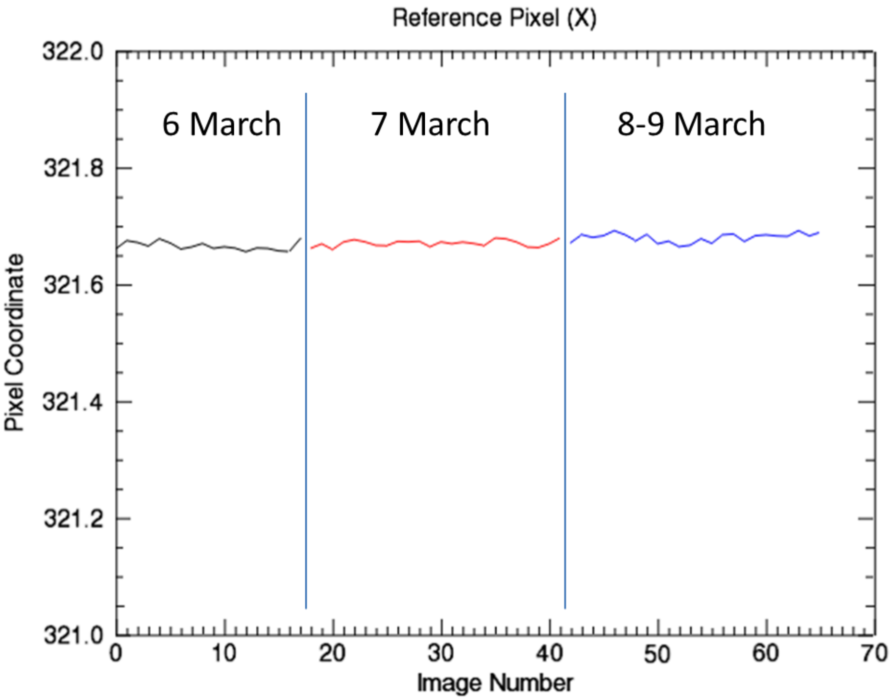
Position of shadow center (reference pixel) was remarkably stable

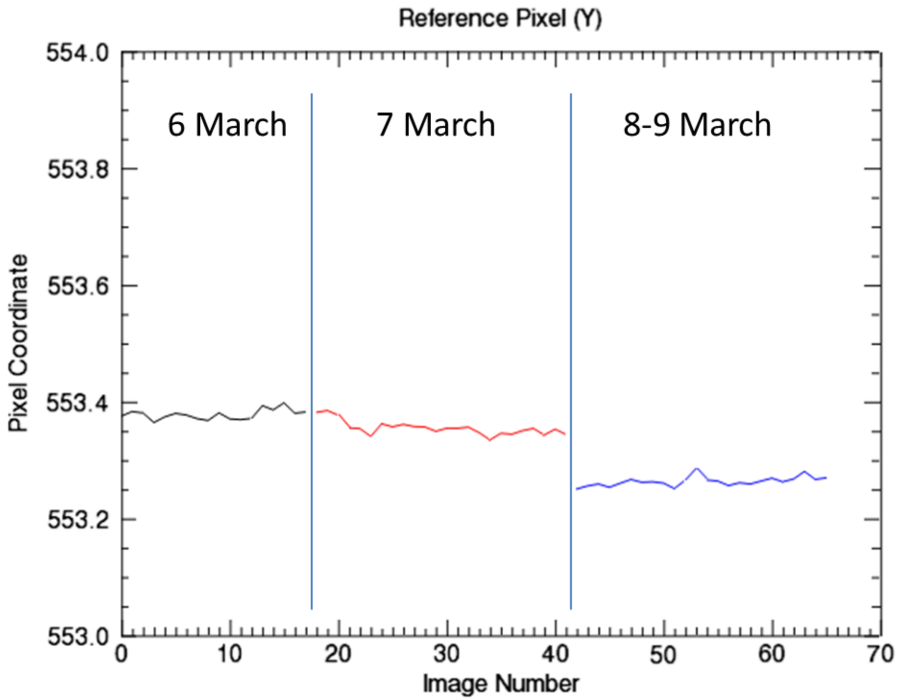
Preliminary evaluation of algorithm on imagery from a recent collection

Date	Start /Stop time	Period (minutes)	Number samples	Exposure (seconds)
March 6	1:13 PM / 6:53 PM	20	18	0.004
March 7	9:27 AM / 8:58 PM	30	24	0.003
March 8-9	12:21 PM / 11:21 AM	60	24	0.003

Imagery was collected in a test lab (B381) on hardware destined for the ARC system at NIF

Reference pixel location was *very* stable

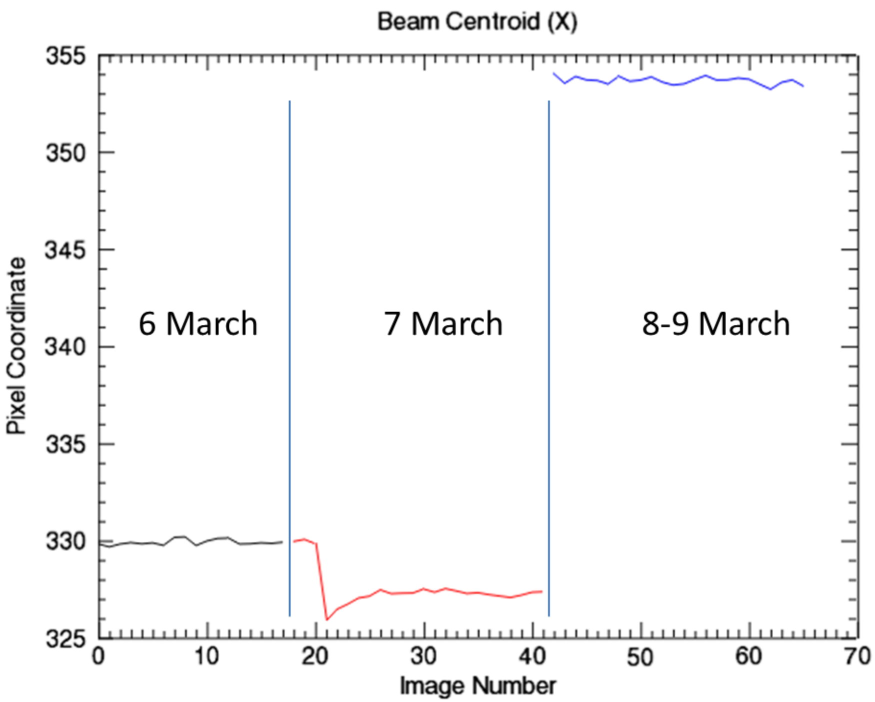


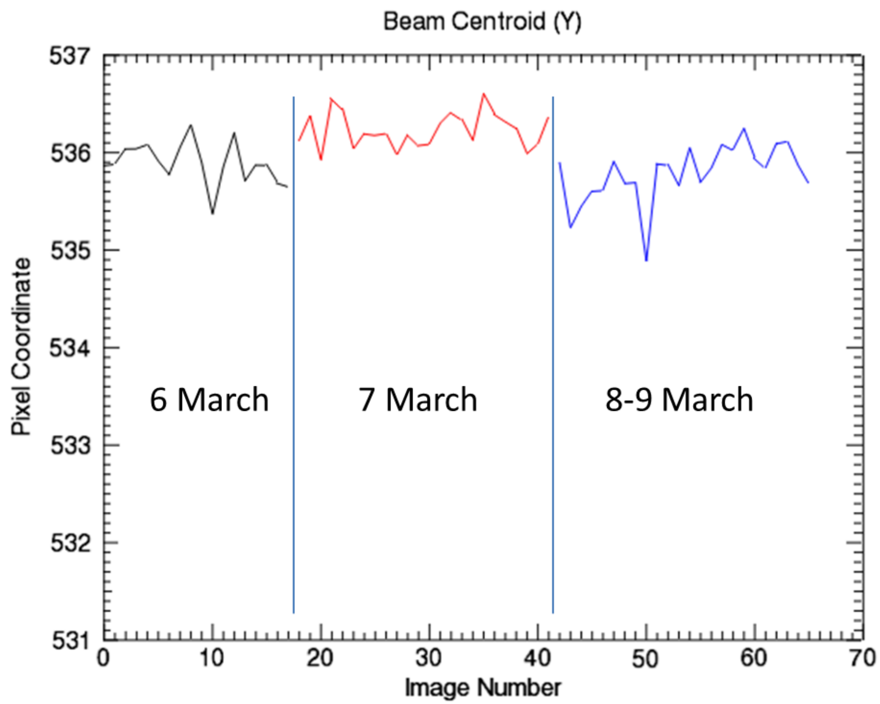


Set 1: Mean = 321.7; std = 0.007
Set 2: Mean = 321.7; std = 0.006
Set 3: Mean = 321.7; std = 0.008

Set 1: Mean = 553.4; std = 0.009
Set 2: Mean = 553.3; std = 0.012
Set 3: Mean = 553.3; std = 0.008

Some minor variations in Beam Centroid, excluding two major glitches





Set 1: Mean = 329.9; std = 0.2
Set 2: Mean = 327.5; std = 1.01
Set 3: Mean = 353.7; std = 0.2

Set 1: Mean = 535.9; std = 0.2
Set 2: Mean = 536.2; std = 0.2
Set 3: Mean = 535.8; std = 0.3

Summary

- Algorithm performs well on the data that we have collected thus far
- From a recent collection:
  - Reference pixel location is very stable
  - Beam centroid moves about a little within a dataset, on the order of tenths of pixels
- New collection will be performed in late-May that will evaluate algorithm performance in a blind test
- Algorithm evaluation will continue as system is built and deployed